

ANALYSIS OF WINTER PRECIPITATION OBSERVATIONS IN THE COOPERATIVE SNOW INVESTIGATIONS

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ABSTRACT

In the Cooperative Snow Investigations of the Corps of Engineers and Weather Bureau, observations were made of precipitation measurements in different kinds of gages and of water equivalent of snow on the ground at a great variety of station sites in the mountains of California and Montana for the five winter seasons ending 1950-51. Much of the variation in catch of precipitation over rugged areas of 4 to 20 square miles is ascribed to variations in local exposure and in natural sheltering of the gages. Wind speed appears to be a good measure of the adequacy of gage shelter and of precipitation catch. The error in sampling of water equivalent for average snow courses is of about the same order of magnitude as the maximum daily change in water equivalent. For seasons of several months' length, observations of gage catch and of accumulated snow on the ground, each at good sites, appear to have comparable precision though there are inherent limitations in the validity of such comparisons.

INTRODUCTION

Some observations of the Cooperative Snow Investigations of the Corps of Engineers and Weather Bureau are organized and displayed with regard to measurements of winter precipitation in mountainous terrain. The data have been published in the *Hydrometeorological Logs* of the Central Sierra and Upper Columbia Snow Laboratories. These Laboratories are described in the Logs and are located respectively in the Sierra Nevada about 40 miles west of Reno at an elevation of 7,000 to 9,000 feet, and on the west side of the Continental Divide near Glacier Park, Mont., at an elevation of 5,000 to 8,000 feet. Maps of the two laboratory areas, and tables describing the station sites are included in the appendix to the present report.

Among the questions that this report is intended to help answer are: What quantitative measures can be assigned to the precision of precipitation and snow pack measurements made under normal but observed field conditions? What is the true variation of winter precipitation over a small rugged area? How much of this variation may be ascribed to weather, large-scale orographic effects, type of gage, quality and frequency of servicing, or physical characteristics of the local site? Where gage catch or snowpack measurements are deficient, how good are they merely as indices to accumulated winter precipitation for forecasting seasonal runoff?

In addition to analyzing the observed data of the Snow Laboratories it is necessary to refer to current views on the subject of measurement of winter precipitation. Current views vary somewhat and almost any plausible view on any issue can be supported by a formidable array of references to earlier work. Context is extremely impor-

tant to this subject, in the strictest sense. Results from one site or set of conditions can be generalized only to a limited degree. Hundreds of experiments have been repeated during the last century with differing environments all over the world. An evaluation of the literature would transcend the scope of this report. Rather than attempting to support each statement not based on Snow Laboratory data, and burdening this report with a long bibliography, two publications will be cited.

One of these publications is that of John Kurtyka, "Precipitation Measurements Study," *Report of Investigation* No. 20, Illinois State Water Survey Division, 1953, and the other, a continuing program under the direction of John Sherrod, is *SIPRE* (Snow, Ice and Permafrost Research Establishment, Corps of Engineers, U. S. Army) *Report* No. 12, "Bibliography on Snow, Ice, and Permafrost," prepared by the Library of Congress, volumes 1 to 6, the latter dated July 1954. These bibliographies are both well annotated and indexed by subject, and contain thousands of pertinent citations.

SOURCES OF AREAL VARIATION IN PRECIPITATION MEASUREMENT

To help view this subject comprehensively reference may be made to table 1, which displays five fundamental categories to which all variation in gage catch may be attributed. The categories are defined partly by the processes used in analyzing them, and are not entirely mutually exclusive. It does not seem possible to measure directly and quantitatively the effects in each category, such as by an analysis of variance. Orographic parameters, for example, are ordinarily defined by analysis of mean seasonal or mean annual precipitation, whereas

TABLE 1.—*Categories of variation in precipitation catch*

	Category	Expressed in terms of:	Examples	Scale	Operates on:	Method of control for estimating areal precipitation
I	Storm experience.....	Storm occurrence.....	Location with respect to storm center.	Miles.....	Storm paths and processes...	Areal sampling.
II	Physlography.....	Orographic parameters.....	Position on, or distance to large mountains.	Miles.....	Condensation processes and falling precipitation.	Stratified sampling of parameters.
III	Environment.....	Double-mass analysis.....	Distance from small ridge...	100's of feet....	Falling precipitation.....	Minimize error by site selection.
IV	Site.....	Rules of thumb.....	Height of nearby trees.....	Feet.....	Falling precipitation.....	Minimize error by selection or modification of site.
V	Gage.....	Gage characteristics.....	Depth and diameter of funnel.	Inches.....	Falling precipitation.....	Minimize error by choice or design of gage and its components.

double-mass analysis requires annual or seasonal totals. The general practice is to standardize the categories near the bottom of the table and to stay within reasonable class limits of the other categories. For example, before orographic parameters can be evaluated the data should first be subjected to double-mass analysis and should be selected from a homogeneous climatic region. How homogeneous the region must be, and with respect to what feature of precipitation regime, is a matter to be defined operationally and with respect to a particular application.

The storm experience category could logically be broken down into detail that would recognize not only storm paths and position of a gage within a storm, but also type of storm (warm front, cold front, orographic, convective, etc.). Further consideration leads to recognition of the seasonal variation in the occurrence and importance of precipitation associated with the respective storm types. These meteorological parameters might lead to a more rational procedure for identifying and defining zones of environment in category II.

Double-mass analysis is useful for identifying changes in the last three categories, and in providing measures of their net effect, but it has limited analytical value. Further study is needed for evaluating category IV, and breaking it down into rational elements. There seems to be a need for objective rules in appraising gage sites. A corollary is the need for definitive criteria for deciding, when a gage is to be moved, whether to change its station designation or to regard the new record as a continuation of the old one. Attention and work have been lavished (in category V) on gage design to a degree that may long ago have reached the point of diminishing returns.

Practical justification for further study of the influences on variation of precipitation catch over an area comes from the needs for improving forecasts of streamflow, design of structures, and other applications. It may be wondered what proportion of the residual error in a forecasting relationship based on average areal precipitation may be ascribed to each of the following sources: imperfect form of functional relationship, inadequate consideration of additional variables, deficient period of record, and errors in sampling precipitation over an area. The first two sources have been subjected to intensive and extensive

trial and error and much ingenuity; the third source is largely a matter of time. The fourth source, quality of basic data, presents an excellent opportunity for fruitful effort at this time. The importance of improving basic data, the significant influence of site characteristics on basic data, and the fact that there has been no conclusive evaluation of site characteristics were among the considerations that led to undertaking and reporting on this subject. The results of the analyses are presented mostly by means of scatter diagrams.

VARIATION AT A SINGLE STATION

Figures 1-4 show how much variation exists within the confines of a single station—that is over distances of a few feet rather than miles. Figure 1 shows daily values of precipitation at Station 1B plotted against those at Station 1C, Central Sierra Snow Laboratory, 1947-48 winter season. The gage at Station 1B is a Friez and that at 1C a Stevens recorder; they are 20 feet apart and on towers. Omitting the data concentrated near the origin, the correlation coefficient is about 0.98, and slight bias is evidenced by the central tendency being above the 45° line passing through the origin. The scatter shows differences due to the different positions of the gages in the forest clearing, differences in the gage shape and mechanism, differences in reading the charts, capping of one or the other gage at times (errors due to capping may affect timing as well as total storm catch), missing record, different quality of servicing from time to time, and additional influences that might be suggested. It would be difficult to separate and measure the proportion of total variation ascribable to each influence. The standard error of estimate is about 0.14 inch, which may be regarded as a good measure of the quality of daily observations of winter precipitation at well-attended gages of this kind.

Figure 2 shows the water equivalent of snowpack on successive days during the 1948-49 season at points 1 and 2 in the Station 1 sampling site at Upper Columbia Snow Laboratory. The correlation here is about 0.98, with a standard error of estimate of about one inch. It is the practice of snow surveyors to report water equivalent to the closest half inch, which seems reasonable in view of this scatter. These two points are about 20 ft. apart, and

"drift" about some during the season to avoid old sampling holes. In order to avoid old sampling holes in a program of daily observations, a fairly large sampling area is necessary. The site used was chosen on the basis of its proximity to other observations near station 1 and its uniform and level terrain, and it was posted to prevent disturbance of the snow. Care was used in programming the observations so as to minimize the confounding of variation of water equivalent from day to day with its variation from place to place, and it is believed that the degree of this confounding is comparable with that inherent in routine snow surveying.

Efforts to separate some of the effects of variation in snowpack water equivalent from time to time among points at the same station include a comparison of variation in snow depth with the variation of water equivalent. In general the coefficient of variation of water equivalent exceeds that of depth by about 50 percent, indicating that considerable variation in sampling water equivalent cannot be ascribed to variation in snow depth.

Most of the snow courses at the Cooperative Snow Investigations Laboratories had from 5 to 10 points, as indicated in the Logs, and their standard error of estimate averaged about 2 inches water equivalent. Attempts to isolate some of the sources of error in water equivalent were made by studying data from the radioactive gage, where the snow is not disturbed, but the variation at this one point was about as great as at an average single point in a snow course. The radioactive gage is described briefly and literature cited in the 1949-50 Hydrometeorological Log of the Central Sierra Snow Laboratory. Its essential feature is the observing of water equivalent without disturbing the snowpack in any way. The gage operates by absorption by the snow mass of gamma rays emitted from a source at the ground surface and observed by a Geiger-Müller tube suspended over the snow above the radiation source. The greater the water equivalent the more absorption and the smaller the gamma count.

Figure 3 shows, for the same period and points as figure 2, the daily changes in snowpack water equivalent. The dispersion indicates a standard error of estimate of about 0.8 inch. It is evident from the scatter that the error is of the same order of magnitude as the change from day to day—a noteworthy fact in considering attempts to estimate daily snow melt by daily changes in water equivalent of deep snow. The points in the 2d and 4th quadrants mark occasions of increase in observed water equivalent at one point and decrease at the other.

The 0.8 inch standard error of figure 3 is not inconsistent with the value of 2.0 given earlier as the general average for the Laboratories. Most of the sites are more rugged than the one where daily samples were taken, and many of the stations were deliberately located to sample terrain features that are usually avoided in routine snow surveying. There was a marked trend of diminishing standard error from year to year because of progressive improvement in marking of the points where individual cores were

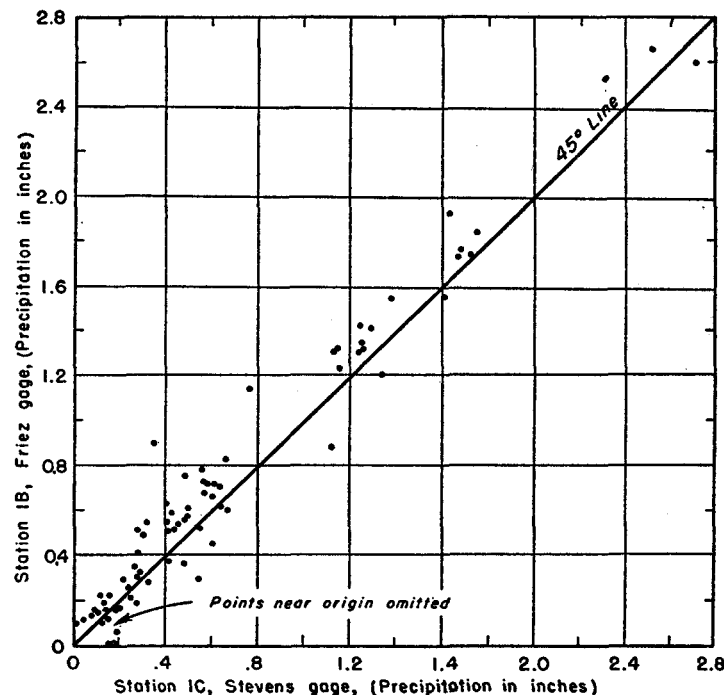


FIGURE 1.—Correlation of daily precipitation at two shielded recording gages 20 feet apart, Central Sierra Snow Laboratory, 1947-48 season.

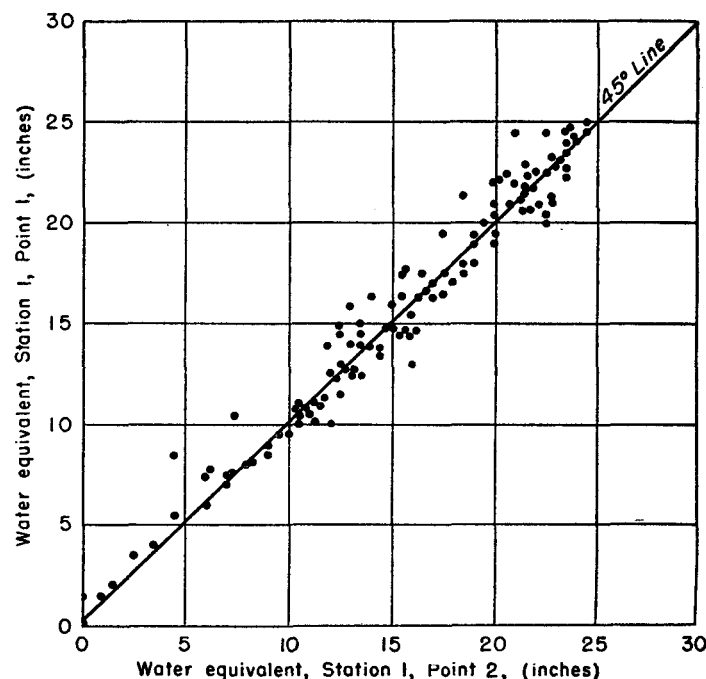


FIGURE 2.—Correlation of daily values of snowpack water equivalent at points 20 feet apart, station 1, Upper Columbia Snow Laboratory, 1948-49.

taken, removing of obstructions such as rocks, smoothing of ground irregularities, and better technique in taking and evaluating individual cores. Decisions whether to accept or reject cores were made objectively on the basis of such criteria as consistent snowpack density throughout the sampling area and high ratios of core length to snow depth. Some snow sampling points were moved after evaluating the effects of drifting or scouring.

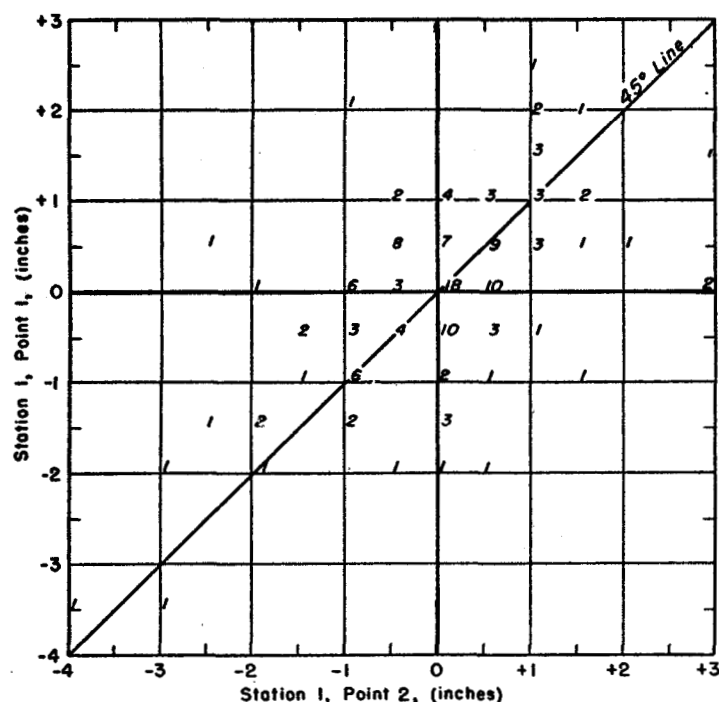


FIGURE 3.—Correlation of daily changes in snowpack water equivalent at points 20 feet apart, station 1, Upper Columbia Snow Laboratory, 1948-49. Numbers indicate the number of observations that might be plotted at each intersection. Observations of water equivalent are made and reported to the nearest half inch.

In addition to decreasing the scatter of the water equivalent observations, the progressive improvement also reduced or eliminated bias at some of the stations. In the few years of laboratory operation there was telescoped the same improvement that has been virtually completed in the course of many years of routine snow surveying practice. It has been suggested that interpretation of some of the older snow survey records may be improved by double-mass analysis.

VARIATION AMONG TYPES OF GAGES

While it is impossible to segregate all the important influences on gage performance, it is worth while to examine some of the data from the battery of gages at Central Sierra Snow Laboratory, for individual storm periods of the 1946-47 season. These gages are only a few feet apart, having been located in general as close as seemed feasible without obstructing one another. Figure 4 shows the respective catches of seven gages, having different combinations of shielding, type of gage, etc. As indicated earlier in comparing gages 1B and 1C, the position within the clearing might account for some of the variation. Complete replication would have been impossible. Noteworthy conclusions are the variation in ratio of catch of paired gages from storm to storm, and the magnitude of their mean ratios to the catch of the gage having the greatest catch. The variation of ratio of catch is illustrated in the comparison of gages 1B and

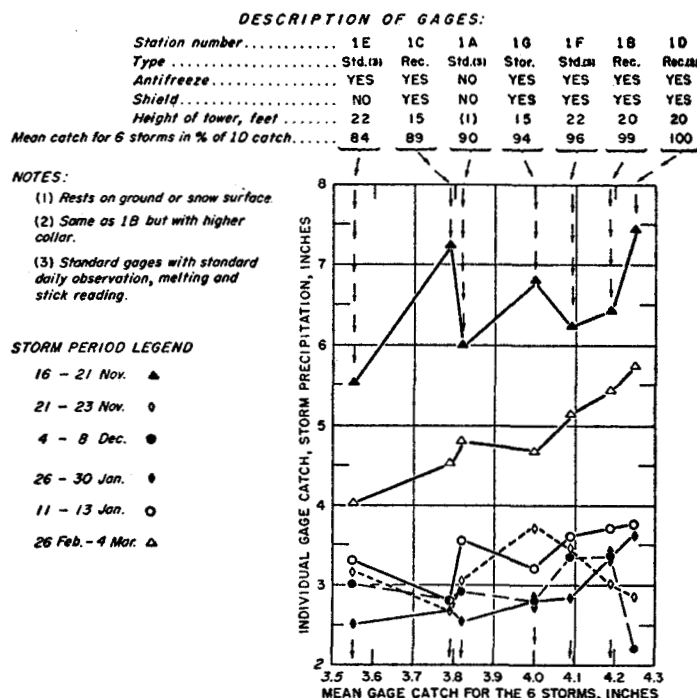


FIGURE 4.—Comparison of catch of seven different types of gage and gage installations, Central Sierra Snow Laboratory, 1946-47.

1C where, in the first November storm, 1C caught 7.2 inches whereas 1B caught 6.5 inches. In the March storm, by contrast, 1C caught 4.5 inches and 1B, 5.4 inches. On the average, the gage catching the least caught 84 percent as much as the gage catching the most for these six storm periods. Many comparisons can be made, and only a few will be cited. The main difference between 1A and 1E, both standard "cans", is that 1A was on the ground or snow surface and had no charge, whereas 1E was on a 22-foot tower and was charged with antifreeze. With daily attendance the charge would not be an important factor. It might be concluded that even with the light wind in this clearing the tower exposure was an appreciable detriment, particularly when the snow was shallow. Gage 1F was different from 1E only in that 1F was shielded. Evidently the shield makes a difference, for this type of gage at this site, of 10 to 15 percent.

VARIATIONS FROM STATION TO STATION, BY SEASONS

Figure 5 shows for each of several gages the respective catches for the two seasons 1946-47 and 1947-48, October through March, Central Sierra Snow Laboratory. The stations are identified by number in the scatter diagram. The average relation shows the 1947-48 season had more precipitation than the 1946-47 season by about 10 percent. Some of the scatter is due to the fact that missing records made it necessary to estimate portions of the

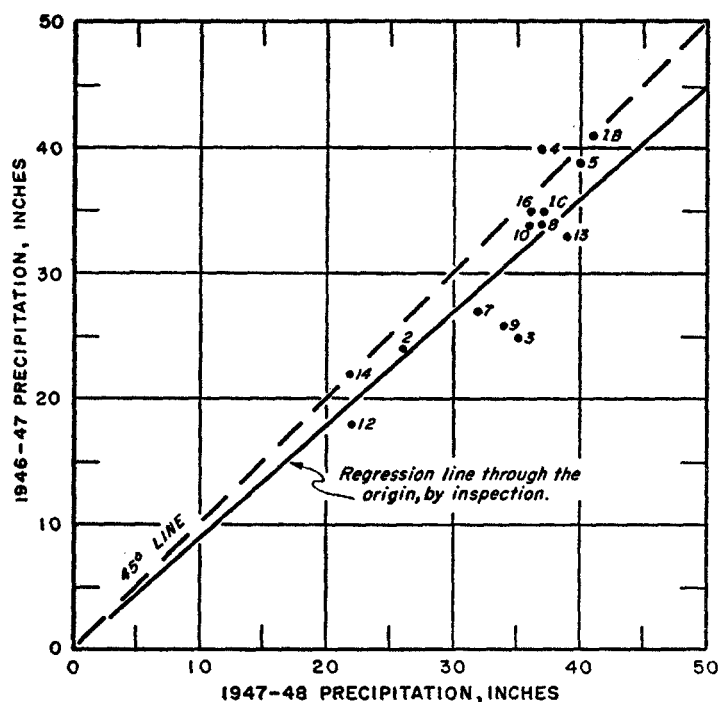


FIGURE 5.—Correlation of precipitation catch of each of several gages (numbers indicate gage) for the 1946-47 and 1947-48 seasons, October through March, Central Sierra Snow Laboratory.

seasonal total, but it is believed that this source accounts for less than one inch in the worst case. The amount of scatter indicates how well or how poorly any one of the gages would serve to locate the regression line, which is another way of saying how well a gage might serve as a consistent index, regardless of true-catch considerations.

An important fact disclosed by this figure is the great range in catch among these gages at Central Sierra Snow Laboratory. They were all on towers and all shielded. They were all within a 4-square-mile drainage area, and had an extreme range of elevation of less than 1,000 feet. Attempts to relate the respective catch of these different gages to topographic parameters of any kind, and in many combinations, were virtually fruitless. Referring again to the five sets of parameters discussed in the introduction, the only explanation is that the variation from gage to gage in Central Sierra Snow Laboratory is ascribable largely to variations in local gage site.

To show how the scatter of figure 5 varies from year to year, instead of merely for the pair of years shown, various pairs of gages have been compared for the 5-year period of record. These comparisons are shown in figure 6. In these graphs the numbers identify Central Sierra Snow Laboratory stations, for the seasons October through March. The solid lines are 45° through the origin and the broken lines are drawn through the origin, fitted to the points by inspection. It is convenient to remember that for most gages the total seasonal precipitation catch increased progressively from year to year, 1946-47 through 1950-51.

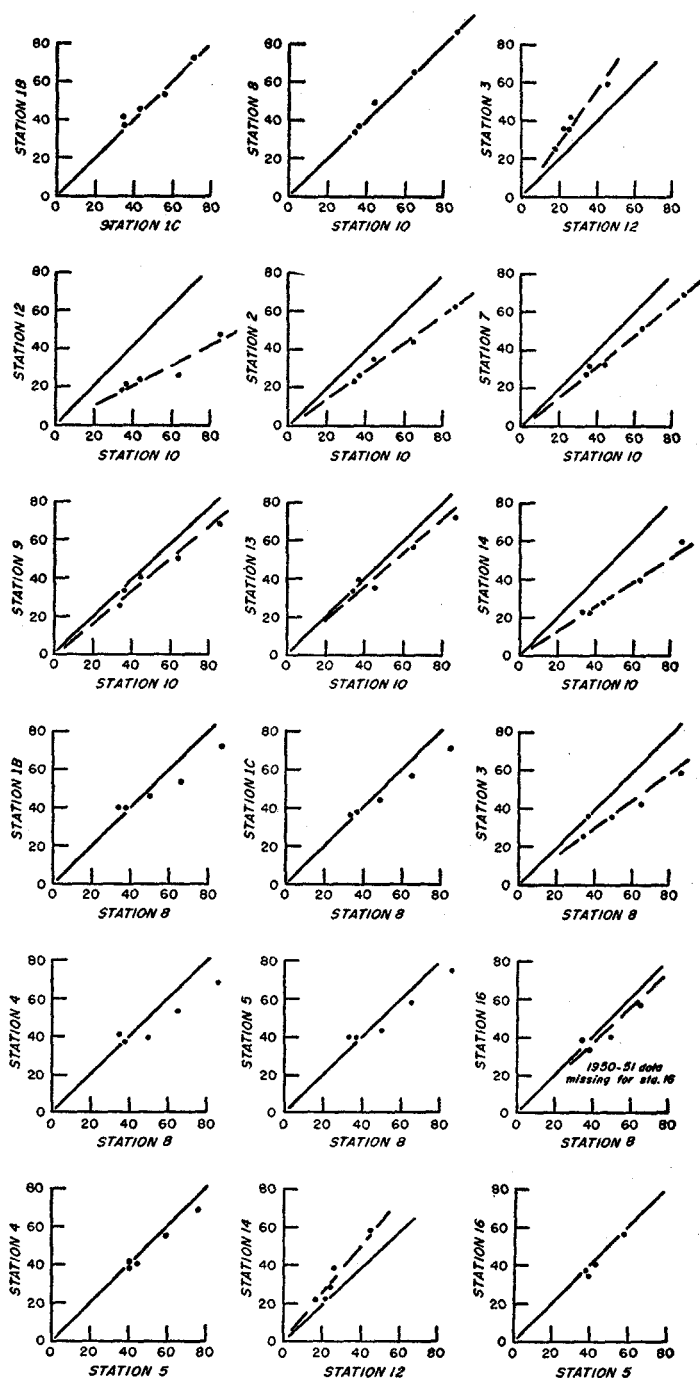


FIGURE 6.—Correlation of seasonal precipitation catch of selected pairs of stations, Central Sierra Snow Laboratory. Each point represents a season, October through March, 1946-47 through 1950-51. The solid lines are 45°, the dashed lines are regressions through the origin, drawn by inspection. Scale units are inches.

Gages 1B and 1C, which have been compared before, appear in the upper left of figure 6. The amount of scatter is small but appreciable. Stations 8 and 10, shown next on the right, show even less scatter than 1B and 1C and it is noteworthy that stations 8 and 10 are 3,000 feet apart with about 200 feet difference in elevation. Even with only 5 years data it is very unlikely that a correlation this high would occur by chance. These two stations are well sheltered by trees and/or concave topog-

raphy. The upper right diagram of figure 6 shows stations 3 and 12, which are respectively in a large flat meadow and on a windy ridge. Neither has much natural protection from the wind. Not only is there more scatter in proportion to their catch than with the previously mentioned pairs of stations, but their catch, particularly station 12, is much less. In general, the stations having the greatest catch have the least scatter when compared with other stations having large catch. It should be said here, as with figure 5, that some of the seasonal totals are based in part on estimated data. Looking at this question pragmatically, errors due to estimating missing records at a station are properly chargeable to that station, but statistically this is a confounding influence because missing record is not necessarily related to the things we are trying to isolate and measure.

It may be seen from these figures how well or how poorly some gages represent others or would serve as indices. While the gage sites are described fully in the 1950-51 Log, it is pertinent to briefly describe some of them here. Station 16 is well sheltered by tall trees, with little sky visible from the gage. Station 5 is well sheltered by low trees and brush. Station 2 is on a ridge, but there are sheltering trees scattered nearby. Station 14 is on a treeless, windy ridge. At the left of the second row of figure 6, is the comparison of stations 12 and 10, which may be regarded as about the worst and best stations, respectively. Station 12 catches about half as much as station 10 does, on the average, with so much scatter that one would hesitate to use 12 as an index to 10, merely by doubling its observed catch.

In addition to the stations shown in figure 6 there are 2 years of record at stations 33 and 34. The stations whose catch most nearly corresponds to that of stations 33 and 34 are 1B, 1C and 7, with very small differences among these 5 stations.

Stations 33 and 34 are under 100 percent forest canopy—deliberately so exposed, just as station 12 was deliberately placed on a windy ridge. It is evident that the deficiency in catch due to interception by the forest canopy is small compared with that due to wind at such stations as 3, 12, and 14. Examination of the site maps and study of the Laboratory data supports some of the recent literature to the effect that the optimum proportions of a forest precipitation-gage site, so as to minimize the combined effects of wind and interception, are a diameter of clearing approximately equal to the average height of the surrounding trees.

Some of the discrepancy in gage catch may be due to the proportions of snow and of rain in the season's catch, with the wind affecting snow catch more than rain catch. About half the precipitation for the 1950-51 season was rain, and about a third of the precipitation for the 1947-48 season was rain. Precipitation for the other three seasons was nearly all snow. The differences among storage, Friez, and Stevens gages are regarded as insignificant in affecting total seasonal catch.

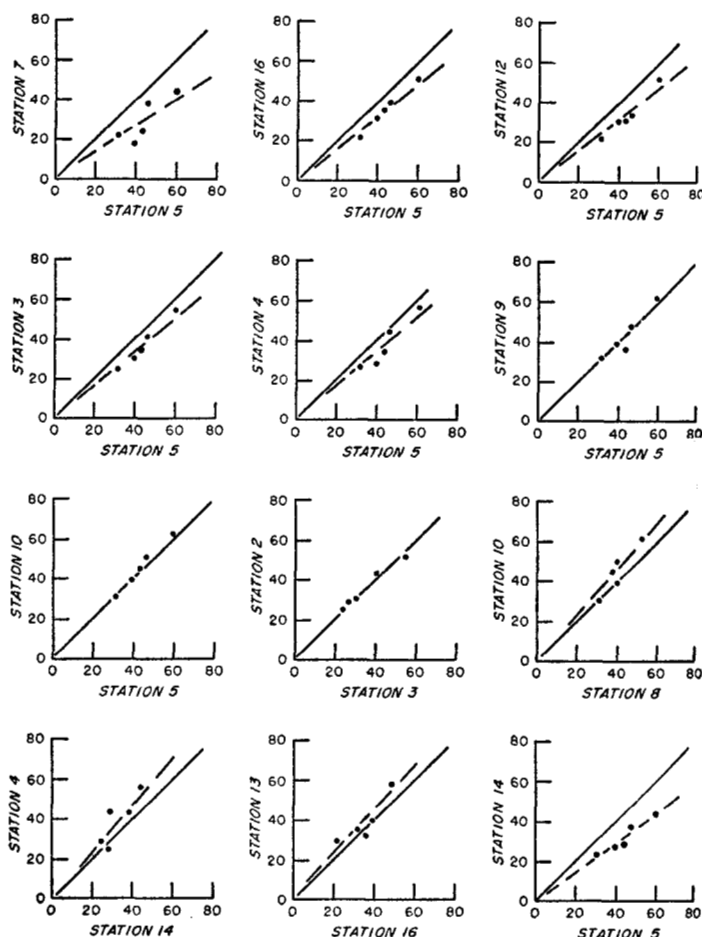


FIGURE 7.—Correlation of April 1 snowpack water equivalent at selected pairs of stations, Central Sierra Snow Laboratory, 1947 through 1951. Each point represents a season's accumulation. The solid lines are 45°, the dashed lines are regressions through the origin, drawn by inspection. Scale units are inches.

Figure 7 corresponds to figure 6, referring, instead of to seasonal precipitation, to water equivalent of the snowpack on or about April 1 each season, Central Sierra Snow Laboratory. In general, the scatter is about the same as for seasonal precipitation. Any difference between the water equivalent and precipitation scatters is probably ascribable to the peculiarities of the individual stations being compared, rather than to inherent differences in the two modes of observing winter precipitation.

Station 7 (upper left) has deficient pack compared with station 5, presumably due to the southerly exposure and early seasonal melting of the snow at station 7. Station 16 (upper center of fig. 7) has less snowpack accumulation than nearby station 5. This difference might be ascribed to interception by the high dense trees at station 16. Station 12 (upper right) and station 14 (lower right) also have less snow accumulation than station 5. Stations 12 and 14 are windy and have scanty ground cover for holding windblown snow early in the season. Speculation among many plausible influences and only a few gages is easy until one faces such facts as station 12 being exposed to the north and station 14 to the south, and being similar

in other important respects. Perhaps compensation exists in the fact that station 12 is on the lee side and station 14 is on the windward side with respect to orographic precipitation. This view is supported by the evidence of figure 6, bottom center, which indicates that station 14 does in fact receive more precipitation than station 12. These diagrams, the data in the appendix, and the more detailed data in the Logs themselves have been examined at length, and further examination will be made by investigators in the future. At present there is no evident, simple, quantitative explanation of just how the many site characteristics operate jointly to influence the accumulation of snow.

Figure 8 shows, for each of the five seasons at Central Sierra Snow Laboratory, scatter diagrams of precipitation catch vs. April 1 snowpack water equivalent. The precipitation is for the period from the beginning of snow cover at station 1, where daily observations are made, until the end of March. The data in figure 8 are subject to some error of interpretation. One source of error is the failure of the beginning date of snow cover at station 1 to properly represent all the stations. Another source is in the need for interpolating among stations where the snow surveys were not made at corresponding dates. Nearly all of the rainfall, which would complicate comparison of gage catch because of limited retention of rain in the snowpack, occurred before the dates of beginning of the seasonal pack.

In figure 8, the degree of scatter is one of the first things to notice. The next thing to notice is the change in position of each station in the pattern from year to year. Some stations retain their relative position better than others. The next thing to notice is the bias, which shows an average excess of snowpack water equivalent of about 15 percent over precipitation catch. This ratio and the absolute difference change from year to year, but no assignable causes were discovered for these changes. The degree of scatter shows that the effects of variation in local exposure are different for snowpack than for gage measurements. As the site maps and photos shown in the Logs indicate, the snow sampling points are usually clustered around the precipitation gage tower. There is, of course, considerable scatter not assignable to inherent differences in these two modes of measurement. A few individual station positions in the scatter may be noted. Station 7, as indicated earlier, and station 19 are exposed to the south and are subject to early seasonal melting. Stations 2, 12, and 14 are deficient both in precipitation catch and in water equivalent, particularly in precipitation catch—possibly because a gage or a tower measurement suffers more from a windy exposure than does a snowpack observation, where the wind is weaker being nearer the ground. Stations 5 and 9 show considerably more water equivalent than precipitation.

Stations 33 and 34, 1949–50, with 100 percent forest canopy over both the gage and the nearby snow sampling points, show slightly more gage catch than snowpack

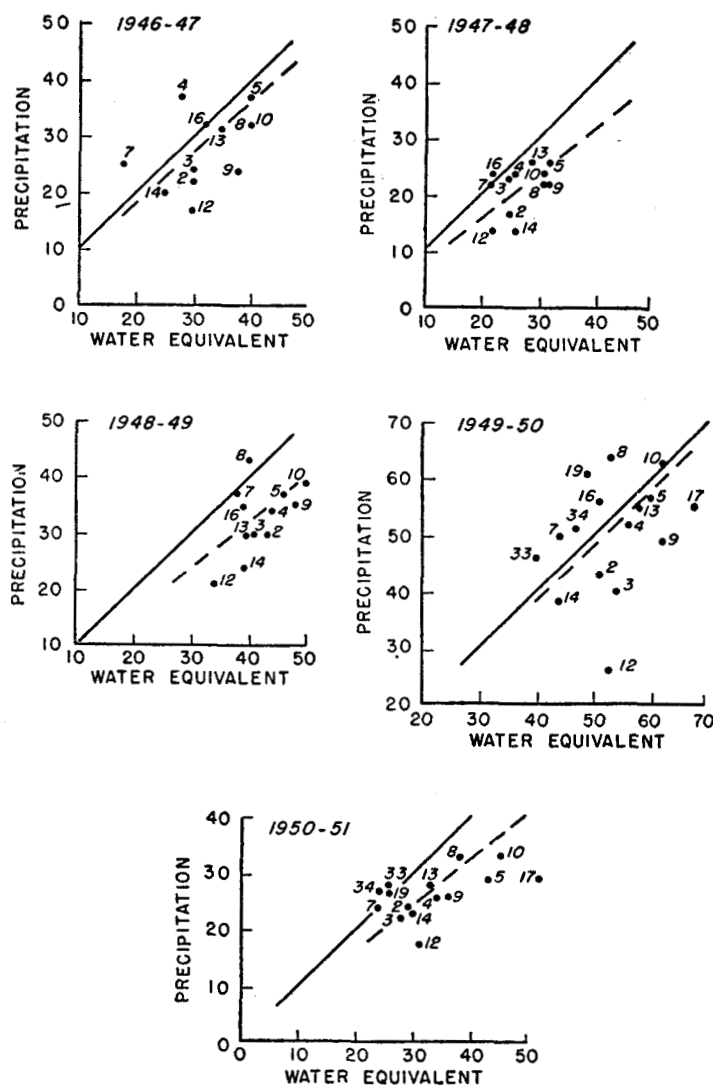


FIGURE 8.—Correlation of April 1 snowpack water equivalent and corresponding precipitation catch for each of the five seasons 1946–47 through 1950–51, Central Sierra Snow Laboratory. Each point represents a station, designated by number. The solid lines are 45°, dashed lines are regressions through the origin, drawn by inspection. Scale units are inches.

accumulation. This difference may be attributed partly to more intercepted snow falling off the branches of the trees into the gages than onto the specific points where the snowpack was sampled. This would be a random error, with no inherent bias. Possibly there is more evaporation from the natural snow surface than from the oil-covered contents of the gage.

Attempts to measure evaporation or condensation, even on a seasonal basis, by comparing snowpack accumulation with nearby gage catch involve several complications. One is the elimination of, or accounting for, snow-melt. Another complication, evident in figure 8, is the combined effect of differences in exposure, errors in measurement, and irregularities in the snowpack. The magnitude of these influences, indicated by the scatter in figure 8, is several inches and obviously obscures the net seasonal vapor exchange at the snow surface—which can hardly exceed five inches in the area studied.

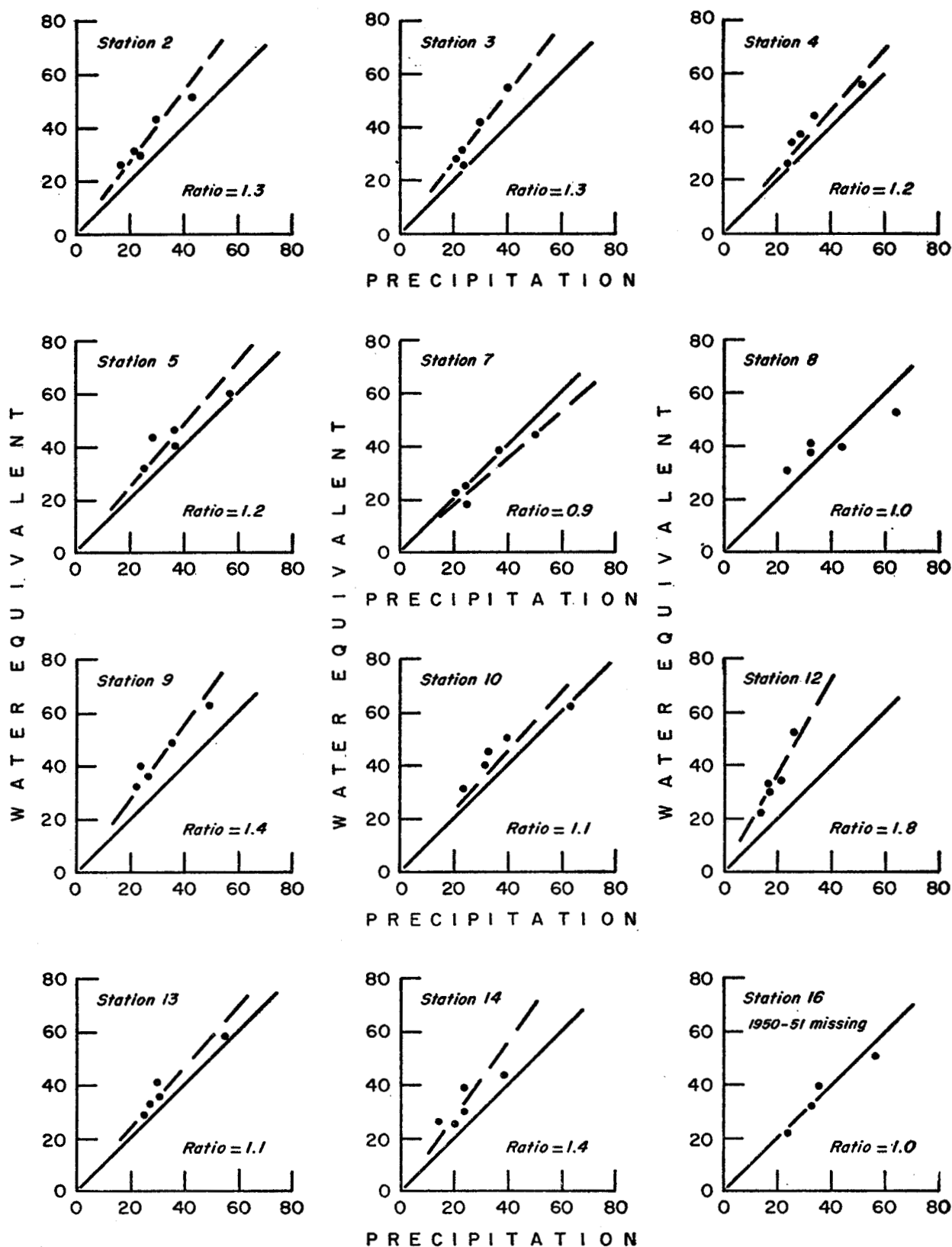


FIGURE 9.—Correlation of April 1 snowpack water equivalent with corresponding catch of snowfall for each of five seasons 1946-47 through 1950-51, by stations, Central Sierra Snow Laboratory. Each point represents a season. The solid lines are 45°, dashed lines are regressions through the origin, drawn by inspection. The ratio shown numerically in each diagram is water equivalent to precipitation. Scale units are inches.

The diminished snowpack under trees has often been ascribed to the evaporation of intercepted snow. It is hard to see why snow held in the tree canopy should evaporate much more than snow accumulated on the ground in open meadows. Possibly the greater snowpack in the open is partly a result of much of the intercepted snow eventually blowing out of the trees into the open by the wind. This snow would be measured by snow courses in the open, but not by gages mounted on towers, and might account for some of the excess of average snowpack water equivalent over gage catch.

Figure 9 shows the relation of precipitation catch to water equivalent at each station, with each year of record being shown by a point in the scatter. These diagrams show the general excess of snowpack over gage catch referred to earlier in connection with figure 8. Attempts to generalize on the basis of particular station features have had limited success. The greatest difference is at station 12, which has been described earlier. The best correspondence is at station 16 where a canopy of huge trees nearly covers both the course and the gage. Water equivalent was not observed at station 1.

It may be noted, in general, from examination of figures 6, 7, 8, and 9, that there is about the same amount of scatter in the year-to-year precipitation catch, year-to-year snowpack accumulation, and snowpack vs precipitation catch at most of the stations, thus indicating no marked superiority in any of the methods of estimating seasonal accumulation of snowfall.

EFFECTS OF WIND

Parts of the foregoing discussion refer to the importance of wind in affecting gage catch, and the question naturally arises: how much of the precipitation naturally occurs during periods of strong wind? Figure 10 shows the relation of daily precipitation at station 1B to mean daily wind 50 feet above the ground at station 3 for January, February, and March 1951. The wind at station 3, while it is 6,000 feet from station 1, is measured in an open meadow and is regarded as a better and more independent indication of daily windiness than the sheltered exposure at station 1. A low but positive correlation (estimated to be about 0.6) is evident. In correlating precipitation with wind it is seen that in spite of a tendency for windiness to decrease the catch, the natural occurrence of precipitation is associated with storms that are accompanied by considerable wind. Thus, wind is important in that it is usually present during significant precipitation.

In spite of examination of many scatter diagrams and trial of many kinds of measures of site characteristics, there was negligible success in an effort to relate precipitation catch to objectively determined site parameters. Elemental parameters that were tried include ratio of diameter of forest clearing to average height of the trees surrounding the clearing in which the gage was located, height of tower above the ground, shape and orientation

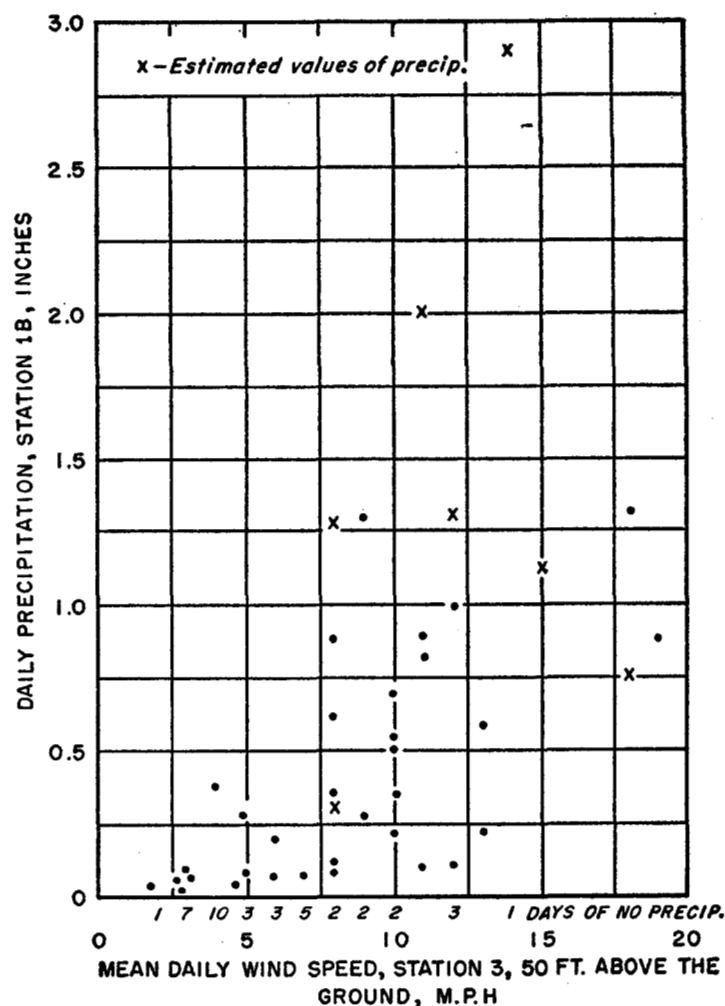


FIGURE 10.—Relation of daily precipitation catch to mean daily wind speed, Central Sierra Snow Laboratory, January, February, and March 1951.

of the clearing, and in the case of more open terrain the distance, size, and direction of obstructions. Enough site elements could be devised to provide a unique solution because of lack of replication, but the essential problem was not solved.

Figure 11 shows a plot of precipitation catch vs wind, by stations. The negative effect of windiness on catch has been noted many times in the literature. A definite negative correlation is evident among the stations each year at Central Sierra Snow Laboratory, the example shown being 1948–49. Except for stations 1B and 1C, where the anemometers are only 8 ft. above the ground or snow, and better sheltered than the precipitation gages, the anemometers are attached to the precipitation gage towers only a few feet from the gage orifices.

It is evident that mean hourly wind speeds of less than 2 to 4 m. p. h. are associated with the stations that have been shown earlier to have the greatest and most consistent precipitation catch. No Central Sierra Snow Laboratory stations other than these shown here have wind speed data for relating precipitation catch to wind speed.

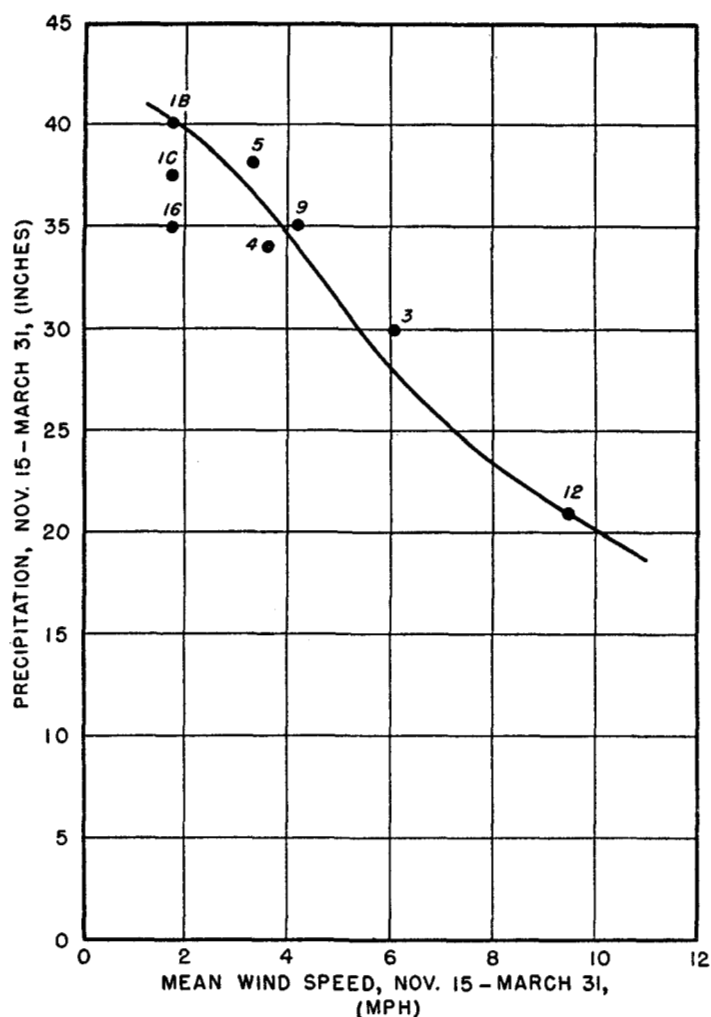


FIGURE 11.—Relation of seasonal precipitation to average seasonal wind speed, by stations (designated by number), Central Sierra Snow Laboratory 1948-49. During publication it was discovered that the point for station 3 should have been plotted at 32 instead of 30 inches of precipitation. The line, however, remains as a good representation of the relation for the several years studied.

Experience at the Laboratories indicates that well-sheltered sites are to be desired, and that windiness is a measure of degree of shelter.

The line in figure 11 was drawn to fit the points, and to meet the requirements of a definite intercept on the Y-axis and an asymptote near the X-axis. While there are too few points in this figure to define conclusively the effect of wind on catch, it is estimated that the correlation accounts for more than half the variance in gage catch among the varying station sites.

CAPPING

Capping is the adherence of snow to a precipitation gage, with the implication of deficient catch because of the cap. There are records of huge caps that envelop and completely obstruct the gage orifice. More frequently, capping only partly obstructs the gage orifice, having the effect of reducing the orifice area. A cap

built upwind on the outside of the gage may not obstruct the opening, but may affect the catch through a change in the aerodynamic shape of the gage. Capping of unattended gages is sometimes evidenced by sharp rises in the pen trace at the time the cap melts and slides down into the receiving bucket.

Capping is difficult to evaluate, and the magnitude and importance of its effects vary greatly according to circumstances. Attempts to generalize on the basis of limited observations have led to controversy. At station 1B at the Central Sierra Snow Laboratory there were an average of six instances of capping each year—some observed and more inferred from examination of the gage charts. In spite of this incidence of capping it may be noted that the seasonal catch seems to have been good.

Other Laboratory stations seem to have had about the same experience as station 1B with regard to capping, but with a few notable exceptions. One type of exception was associated with experiments in using timber for gage towers. Large-size structural members have an excessive horizontal projection of surface on which snow can accumulate and build up to effective caps. The other type of exception might not be regarded as true capping, but resulted from using towers that were too low, and there were instances, while getting acquainted with the weather at the Laboratories, of deep snow completely covering the tower and gage.

In general, the laboratory experience showed that extreme windiness had more effect on gage catch than did capping or any other process. It is possible that unattended storage gages have at times had deficient catch incorrectly attributed to caps that were observed when the gages were serviced, rather than to the less obvious but persistent wind—particularly at poorly sheltered sites.

At a well-sheltered site a cap may build up but will eventually contribute to the gage catch as the sharp orifice rim cuts its way through the settling snow of the cap—essentially taking a snow core upside down. At such sites, there is too little wind to blow the cap off the gage and lose it from the catch. The error from capping is then one of timing rather than of total catch.

Efforts to treat gages with hydrophobic or anti-icing materials have had little success. There have been many experiments with heating the orifices of gages, with some reports of success, and other reports that the heating causes evaporation of the incipient cap, with as much loss as from the effects of the cap itself. There is fairly general agreement that frequent servicing is very helpful. Instead of waiting for the cap to cut its way into the gage, servicing of the gage includes gentle pushing of the snow cap into the receiving bucket. At the Snow Laboratories servicing was at monthly or more frequent intervals.

Present practice with storage gages is to use flexible shields so that movement of the leaves by the wind shakes off snow that might otherwise build up into a cap. For

snow that accumulates at the orifice of the gage instead of the shield, some melting of the cap is induced by absorption of solar radiation by black paint used on the gages. At sites having adequate natural shelter—small clearings in a forest—shields are unnecessary. Such sites are relatively shady until late in the spring so that black paint would have little effect.

GAGE SITE

The conclusion that a small clearing is best for gage exposure appears to be at variance with the traditional rule that a gage should be no nearer an obstruction than two or four times the height of the obstruction. This old rule evidently applies to single large obstructions, such as buildings, and not to a symmetrical opening in a forest or orchard.

It is evident that shielding does little to improve an inherently poor gage site. It is also evident that variations in natural winter precipitation over distances of a few miles and with elevation differences of a few hundred feet are very small compared with the variation in catch ascribable to differences in local site. Therefore, subject to convenient accessibility for observation and servicing, a gage can sample the storm experience and large-scale orographic parameters, and still be located anywhere within a rather large area provided the site is well sheltered.

The choice of gage site might be aided by means of a small portable anemometer, tying in the short-period wind data with a central station, just as with altimeter surveying. A time may come when shields will rarely be necessary or justified, and, whenever a windy site must be used, a correction factor in terms of the windiness of the site can be applied to the precipitation catch, just as corrections are now made for height of anemometer.

INSTRUMENTAL PRECISION

In discussing the effects of weather and physical exposure on measurement of winter precipitation it is pertinent to refer briefly to the inherent precision of the measuring instruments.

The spring scales used for weighing snow cores can seldom be read with a precision of much better than a half inch of water equivalent. This is particularly true of the light cylindrical type of scale in common use because of its convenient portability. This degree of precision is consistent with the sampling error of water equivalent. The dimensions of snow cutters and tubes commonly used are adequately precise.

The weighing mechanism of most recording precipitation gages is precise to about one hundredth of an inch. This degree of precision is required for measuring light rains and is more than adequate for measuring precipitation in the form of snow. The receiving ring of standard and recorder gages is usually dimensionally exact when new, but occasional attention may be necessary to keep

it round. Possible variation in the dimensions of individually fabricated conical Sacramento-type storage gages make it advisable to inspect each gage, and to calibrate it for corrections to the published tables of volume vs. depth of catch. The enlarged diameter at the bottom of the Sacramento gage makes observations by stick reading subject to considerable error until sufficient precipitation has raised the depth of liquid in the gage. Standpipe storage gages have good balance between inherent quality of the observation and precision of stick reading for all depths. The standard 8-inch diameter by 24-inch high gage, with stick and measuring tube, has more than adequate precision for measuring snowfall—whether it is caught in the gage or whether the “can” is used for cutting a core of shallow snow.

CONCLUSIONS

Some of the statements appearing in table 2 and the discussion following it will be identified as originating with these analyses of the Snow Laboratory data. Other statements are not supported by analysis appearing in that report, but represent undocumented laboratory experience and are included mostly to make the report fairly comprehensive.

In general, the experience at the Laboratories confirms much of the present generally accepted opinion on the subject. Amplification of the general body of knowledge includes an evaluation of the observational error in gage catch and water equivalent. Contrary to widely held opinion, there seems to be convincing evidence that most of the variation in precipitation and water equivalent may be attributed to variations in the local exposure of each observing station, and that the annual pattern of “true catch” over rugged areas as large as 10 sq. mi. is relatively flat. The only weather elements that seriously affect measurement of winter precipitation are wind, and, secondarily, elements combining to cause freezing, or—with snow surveys—also heating. The average observed water equivalent is apparently very nearly a measure of its true value. The average observed precipitation for all the laboratory gages was about 15 percent deficient, due almost entirely to the effects of wind on the relatively high gage towers that are necessary in places where deep snow-packs accumulate. The laboratory gages exposed with the best shelter, stations 8 and 10 of Central Sierra Snow Laboratory, for example, appeared to have very nearly 100 percent true catch. Variation due to type of gage is fairly small, with the important conclusion that the effects due to differences in gage, including shielding, are much smaller than the effects of physical features of local station site.

Only a little has been said about frequency of servicing as an influence on quality of data, and it would be hard to assign it a measure but it should be emphasized that the laboratory experience showed definitely that frequency

and skill of servicing is extremely important—not only for reducing relatively small so-called random error, but to reduce loss of record. Nearly all the extraneous influences on gage catch tend to reduce it, and the generally held opinion that the most catch is the best catch seems to be supported, except in the case of obvious blunders in exposing a gage. The laboratory data show rather definitely that the gages with the poorest catch also are the most erroneous with respect to having index value.

TABLE 2.—*Effects of principal weather and exposure elements on precipitation and snowpack measurements*

Element	Effect on gage catch	Effect on snowpack water equivalent
Weather:		
Wind:		
Drifting snow.....	Nil, gage on tower.....	Increases small-scale variability. ¹
Turbulence.....	Deficient catch ¹	Increases small-scale variability. ¹
Melting:		
Solar.....	[Melting is beneficial and the melt water is retained in impervious gage.]	Early spring melting loss on south slopes. ^{1,2}
Warm soil.....		Little late-fall melting loss. ^{1,2}
Warm air.....		Early spring melting loss at low elevations. ^{1,2}
Vapor exchange:		
Condensation.....	Very slight in gage.....	Small gain to pack. ^{1,2}
Evaporation.....	Nil, with oil film.....	Small loss from pack. ^{1,2}
Rainfall.....	Normal part of catch.....	Part may pass through pack. ^{1,2}
Freezing:		
During deposit.....	Capping and loss of catch ¹	Makes measurement difficult.
After deposit.....	Makes measurement difficult. ¹	"Corky" snow with loss of core. ¹
Exposure of site:		
Obstructions:		
Interception.....	Slightly deficient catch ¹	Same as for gage.
Sheltering.....	Helps reduce bad wind effects. ¹	Reduces small-scale variability.
Retention.....	Does not apply to gage.....	Excess pack due to snow-fence effect. ¹
Soil surface:		
Roughness.....	Does not apply to gage.....	Increases small-scale variability. ¹
Slope.....	Small effect on gage.....	Small effect on pack. ¹
Permeability.....	Does not apply to gage.....	Loss of melt water or rain. ²

¹ Item is important and is discussed in text.

² Item raises question of purpose of measurement: Would be detrimental to the measurement as an index of seasonal precipitation but inherent and necessary in a measurement of snowpack as such where the interest is essentially in the residual pack regardless of its history.

Discussion of important effects of weather and exposure on gage catch:

Wind turbulence.—May cause loss of more than 50 percent, even on a seasonal basis; shielding may help as much as 20 percent, but best solution is better choice of natural site so as to take advantage of sheltering effect of surrounding trees, etc., and reduce the mean wind speed to less than about 2 m. p. h. at the gage orifice.

Capping.—Serious in some instances; frequent servicing helpful, also nature of gage: black paint, good shape, etc.; experiments with hydrophobic coating, heating, and vibration have been unsuccessful to date. Frequency of occurrence is difficult to estimate. Many small caps melt their way into the gage and do not affect the total catch

of a well-sheltered gage, but adversely affect the timing with recording gages.

Freezing after deposit.—Makes stick measurement difficult but is not serious if the gage has ample capacity. Antifreeze helpful; occasional servicing reduces stratification.

Interception.—Reduces seasonal catch at most about 15 percent in the environment studied.

Sheltering.—While large single obstructions are harmful, and express wind direction as well as precipitation in nearby gage catch, a gage, exposed in a symmetrical forest or orchard clearing having a diameter about equal to the height of the trees, will gain more from the reduction of wind effect than it will lose from interception.

Drifting snow.—The effects of drifting and drifted snow, and of wind turbulence, may all be grouped under one heading. The net effect is less near the ground than at the usual height of a gage on a tower. The effect is minimized by using a large number of points per course; no bias seems evident.

Solar melting.—On south slopes, melting may occur so early in the season that such a course would not be representative for estimating water supply.

Warm soil.—The loss from a snowpack due to warm soil is usually very small, and would not be a serious deficiency with respect to water-supply forecasting except in instances of intermittent snow cover for much of a normally long snow-cover season.

Warm air.—At low elevations early season melting may reduce the snowpack water equivalent to a degree making it nonrepresentative for water-supply considerations. As a measure of existing snowpack, for considering its effect on runoff from rain in flood forecasting, low-elevation snow data is very helpful.

Condensation and evaporation.—These elements often balance and probably seldom exceed five inches water equivalent loss or gain for a season.

Rainfall.—The capacity of a snowpack for storing rain or even melt-water is usually less than 5 percent of the water equivalent of the snowpack.

Corky snow.—As with capping of a gage, the cause is the sticking of snow to the measuring instrument because of freezing of water in the snow. Skill in making the measurement is helpful, but there are times when wet snow in the pack is chilled and plugs the tube so that a satisfactory core is impossible. It is difficult to estimate the frequency of occurrence of serious trouble from corky snow. Some regions rarely have it.

Retention by obstruction.—At some sites low brush and weeds may produce a snow-fence effect wherein excessive and nonrepresentative pack may accumulate early in the season until the brush is enveloped. This effect is seldom serious, but can be controlled as can the effects of rough ground and rocks by proper preparation or selection of the site.

Soil surface roughness.—Similar to the above discussion

of obstruction. Even a smooth-looking ground surface may have a standard deviation of elevation of two or three inches within a few feet of a snow stake. The deposited snow tends to have a more streamlined shape than the ground surface so that the thickness of the snowpack may have considerable variation over very small distances. While several points are necessary for good sampling of a snow course, the points do not need to be as far apart as has been the practice.

Soil slope.—Ponded water makes it important to avoid marshy areas and drainageways. Steep slopes are to be avoided, also places where there is a sharp change in

slope, because of irregularity in the downhill movement of the snowpack and because of damage to, or loss of, the snow stakes affected by the mass movement of the snow.

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APPENDIX

The tables and maps on the next four pages presenting general characteristics and locations of the stations at the Central Sierra and Upper Columbia Snow Laboratories were taken from the *Hydrometeorological Logs* of the Cooperative Snow Investigations. The background, organization, and objectives of the investigation, with brief descriptions of each of the field laboratories and tables showing the instrumentation and observational program, have been given in *Technical Report 6-4* of the Cooperative Snow Investigations.

A *Hydrometeorological Log* has been published for each water year (begins October 1) of record for each of the laboratories. Each log has a brief text, a topographic map of the laboratory area, a bar chart showing the availability and status of observational data, a summary of the stations and types of data for each water year, a graphic synopsis of daily values of selected representative elements, and an average of 200 pages of numerical data. Some of the logs present special summaries and tentative results of the revisions. The logs of 1950-51 for the Central Sierra Laboratory and of 1948-49 for the Upper Columbia Laboratory contain detailed station site maps and pertinent photographs. In all, about 2 million

observations are tabulated in the logs. A few additional tabulations and all the original field notes and recorder charts are on file. Considerable selected data are on punch cards. Questions about quality, circumstances, and selection of data; about availability of unpublished data; or about reports other than the logs, may be referred to the Division Engineer, South Pacific Division, Corps of Engineers, U. S. Army, San Francisco, Calif., or to the Chief, Hydrologic Services Division, U. S. Weather Bureau, Washington, D. C.

While this report is a description of some of the effects of winter weather and exposure on the performance of precipitation gages, it may be of interest to note the other elements that have been measured and are recorded in the logs: incident and reflected solar radiation; air temperature and humidity at many stations and at various heights above the ground or snow surface; snowfall, snow depth, water equivalent, density, and other snow properties at many stations; stream flow and ground water stage; snow, soil, and water temperatures; wind speed and direction; soil moisture; barometric pressure; and weather (cloudiness, etc.).

SUMMARY OF STATION SITE CHARACTERISTICS CENTRAL SIERRA SNOW LABORATORY											
1	2	3	4	5			6		7		
Station Number	Elevation Feet	Slope %	Aspect Az	Exposure Sector			Shelter Sector		VEGETATION AND REMARKS		
				Azimuth Limits	Dominant Direction	Size Arc	Lowest Point	Size Arc	Highest Point	Canopy Cover %	
1 (Hq.)	g.b. 6895	10	270	170-270	SW	100	120	260	585	15	(7) Open area approximately 150' diameter.
	sh. 6885	15	250							25	(7) Open area approximately 50' diameter.
	py. 6885	10	210							10	(5) On North side of open area approximately 100' diameter. In area of exposed bedrock.
2	7525	10	310	220-20	NW	160	525	200	145	10	(3) Partially within small open grove. Some points shaded by trees. Near top of ridge.
3	7170	<5	200	220-250	SW	30	100	330	430	<5	(1) In North part of grassy meadow. Refers only to Met. Sta. and snow course.
4	7245	5	330	50-100 230-280	SW	100	75	260	305	10	(3) Among scattered trees and small open groves. Some points shaded. Irregular surface of bedrock and boulders.
5	g. 7370 sc. 7375	5	170	130-160	SE	30	120	330	530	5	(4) Willow thickets near all points, covered by snow in winter. Small trees near points 1 and 2.
6	7835 7905	25	200	90-290	S	200	460	160	310	10	(3) Part of course among bedrock outcrops and small boulders.
7	g. 7170 sc. 7155 - 7225	20	180	70-240	S	170	310	190	405	25	(8) Many boulders and outcrops of bedrock near points.
8	points A-E and gage 7740	5	130	100-170	SE	70	440	290	475	<5	(3) F, G, H on rocky slope.
	points F - I -7810	30	190								Bedrock outcrops near K and L.
	points J - L -7785	20	40								
9	g. 7510 sc. 7505	<5	190	160-230	S	70	335	290	490	<5	(1) Point 6 near willow thickets.
10	g. 7570 sc. 7565	15	200	140-210	S	70	215	290	810	5	g. (7) sc. (5) Snow course at base of 30% slope.
11	7290	25	200	100-130 180-260	SW	110	215	250	375	5	(7) In open area approximately 150' in diameter, open toward SE.
12	g. 7550 sc. 7555	15	330	250-80	N	190	400	170	155	<5	(3) Far from forest. Scattered trees and small open groves. On spur 150' lower than main ridge.
13	g. 7035 sc. 7040	g. <5 sc. 5	g. 260 sc. 130	180-250	SW	70	165	290	440	<5	g. (6) Gage in willow thicket near Castle Creek. sc. (7) Part of snow course among granite boulders.
14	7480	20	220	90-280	S	190	255	170	495	<5	(3) Among low shrubs and outcrops of bedrock.
15	8260	35	200	120-300	SW	180	770	180	840	0	(1) On crest of barren rocky spur.
16	g. 7510 sc. 7505	30	70	80-140	E	60	210	300	705	40	(9) In old growth fir.
17	g. 7745 sc. 7740	15	110	80-170	SE	90	345	270	470	<5	(1) On small bench of approximately 10% slope. Slope below site 15-20%.
18	7850	28	190	130-220	S	90	375	270	1250	15	(7) Points A, B, H, G shaded by trees.
19	7340	10	160	70-230	S	160	365	200	480	25	(7) In small open area. All points shaded by trees. Snow course among outcrops of bedrock.
20	7325	20	350	280-40	N	120	250	240	375	10	(7) Points C and D shaded by trees.
21	7780	15	220	170-280	SW	110	355	250	1020	15	(7)
22	7395	15	60	90-130	E	40	220	320	405	5	(7) Points E and F shaded; F under forest canopy.
25	7300	5	130	0	SE	0	0	360	340	10	(9) Shelter cabin.
26	7310	<5	130	110-150	SE	40	100	320	360	10	(1) Station in lower end of meadow, frequently marshy.
27	8245	50	200	130-280	S	150	720	210	860	0	(1) Rocky slope. No trees within 1,000'.
28	6910	10	150	150-270	SW	120	140	240	490	20	(8) Among boulders and bedrock outcrops.
29	7525	5	170	120-210	S	90	300	270	575	5	(7)
30	7350	20	340	0-60 250-340	N	150	380	210	320	10	(9)
31	7190	10	320	240-270	W	30	100	330	510	10	(9)
32	8000*	50	170	130-200	S	70	480	290	1100	10	(1) Rocky Slope. Small grove of tall trees 25' northeast of gage. Nearest tree about 25' from gage.
33	7415*	20	240	140-170	SE	30	170	330	560	20	(9) Closed canopy fir forest.
34	7040*	5	230	190-250	SW	60	290	300	410	20	(9) Closed canopy lodgepole pine forest.

LEGEND AND DEFINITIONS

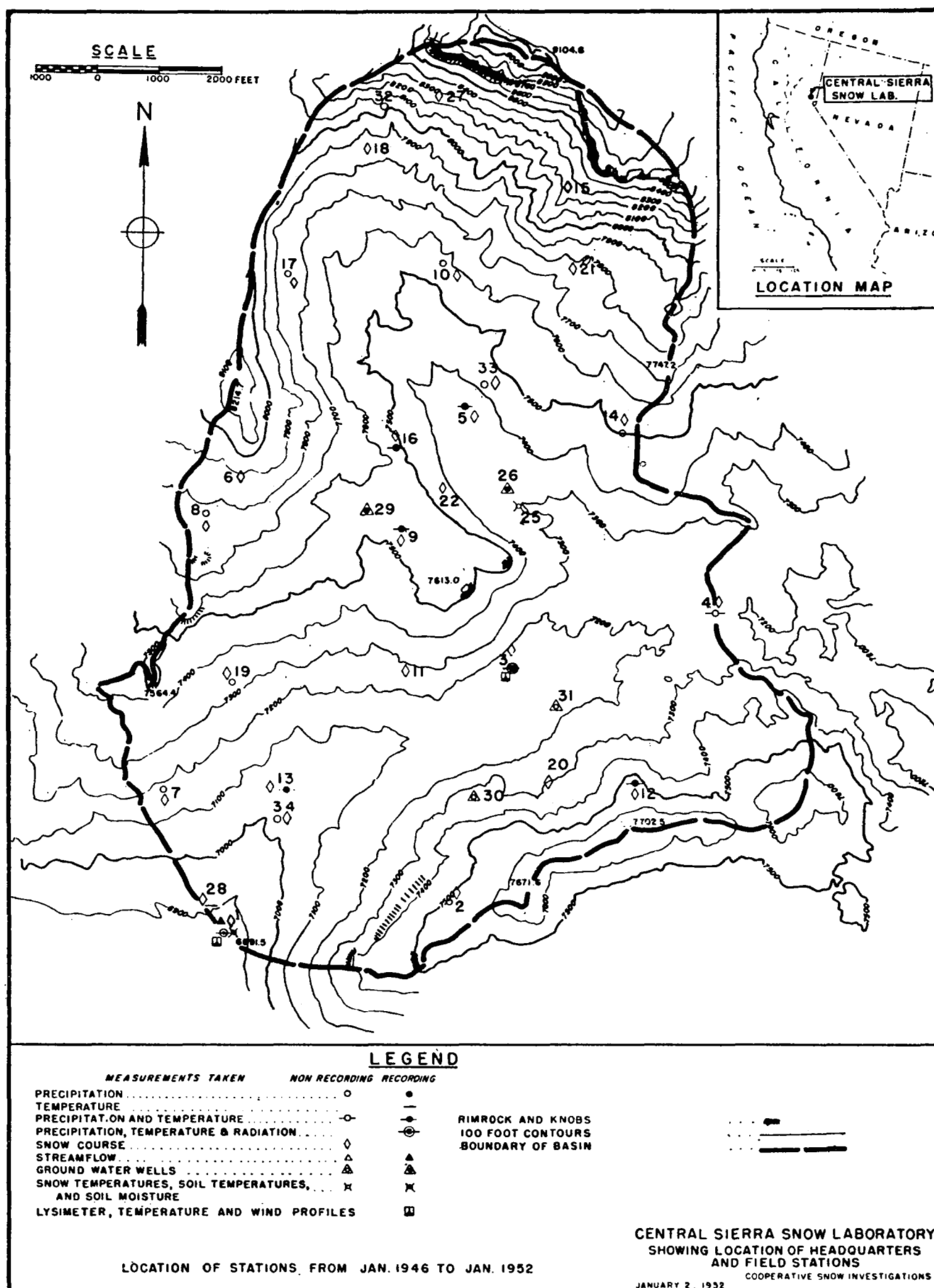
Column

- 2-4 Values are means for installation area, except in cases of marked variation.
- 2 Elevation in feet above m.s.l. g = ground elevation at precipitation gage. sc = mean elevation of points in snow course. To nearest 5'.
- 3 Slope: Dip of surface over horizontal interval of 200'. To nearest 5%.
- Vertical interval
Slope = $\frac{\text{Horizontal interval}}{\text{Horizontal interval}} \times 100$
- 4 Aspect: Orientation of slope to nearest 10° Az. Az = clockwise angle from true north.
- 5 Exposure sector: That sector of a circle of 1/2 mile radius, centered in the installation area, within which there is no land higher than the station. Azimuth limits of sector to nearest 10°. Dominant direction of exposure to nearest 10° compass points. Angular size of sector in degrees. Lowest point = elevation difference between station (at gage) and lowest point in exposure sector, to nearest 25'.
- 6 Shelter sector: That sector of a circle of 1/2 mile radius, centered in the installation area, within which there is land higher than the station. Size = 360° - size of exposure sector. Highest point = elevation difference between station (at gage) and highest point in shelter sector, to nearest 25'.
- g : Precipitation gage. g.b. : Battery of precipitation gages.
sc : Snow course. sh. : Instrument shelter, mast and snow stake.
* : Estimated. py : Pyrheliometer and Lysimeter site.

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Column 7

- Canopy cover: Tree canopy cover within a circle of approximately 400' diameter, approximately centered in the installation area. To nearest 5%. From aerial photos.
- The following vegetation characteristics refer to an area within 100' of the points of the installation.
- (1) Away¹ from forest margin; ground clear.
 - (2) Away¹ from forest margin; thickets.
 - (3) Away¹ from forest margin; scattered trees.
 - (4) Away¹ from forest margin; thickets and scattered trees.
 - (5) Near² forest margin; ground clear.
 - (6) Near² forest margin; thickets.
 - (7) Near² forest margin; scattered trees.
 - (8) Near² forest margin; thickets and scattered trees.
 - (9) Within forest.
1. Margin of relatively dense forest >100' from most or all of the points.
2. Forest margin <100' from most points.
- Open area: Non-forested area.
- Shaded by trees: Trees cast shadow over sampling point at times during middle part of day.
- NOTE: Not all stations listed above were active during the 1951-52 water year. See "Status of Laboratory Observations" for current year.



SUMMARY OF STATION SITE CHARACTERISTICS UPPER COLUMBIA SNOW LABORATORY										
1	2	3	4	5			6		7	
Station Number	Elevation Feet	Slope %	Aspect Az	Exposure Sector			Shelter Sector		VEGETATION AND REMARKS	
				Azimuth Limits	Size Arc	Lowest Point	Size Arc	Highest Point		
1	A 4960	25	230-350	20-40 240-280	60	W	200	300	600	(5) On crest of west sloping ridge. Anemometer above tops of adjacent trees, except to the east.
	B 4840	5	(270)	240-270	30	W	100	330	725	(2) Most points <25' from forest margin.
	C 4845	5	(270)	240-270	30	W	100	330	725	(2) All points <25' from forest margin. Points 1, 3 subject to shading. Points <10' above Skyland Creek. Near foot of 25% slope.
A - H	4845	<5	(230)	240-270	30	W	100	330	725	(5) Beneath canopy of young pine forest.
2	4825	5	(150)	240-270	30	W	125	330	875	(2) Most points <25' from trees. Points 1-4, 9 subject to shading. All points <5' above Bear Creek. Points 7-11 subject to flooding. Subject to road dust contamination.
3	5225	-	-	100-170 250-20	200	W	375	160	675	(6)
4	5360	10	340	200-120	280	NE	150	80	400	(2) All points <25' from forest margin.
5	5175	-	-	120-10	250	SW	675	110	375	(3) Most points <25' from forest margin. Points 1-3 subject to shading. Clearing partly occupied by pond in spring.
6	A 6310	30	210	140-40	260	SW	650	100	250	(3) Points 2, 3, 4 <25' from forest margin and subject to shading.
	B 6315	15	220	140-30	250	SW	625	110	275	(3) All points <25' from forest margin. Points 2, 3, 5, 6 subject to shading.
	C 6320	30	160	130-290 350-30	200	SW	625	160	275	(3) Points 1-4, 7 <25' from forest margin. Points 1, 2, 3 subject to shading.
8	7155	20-35	260	110-310	200	SW	850	160	400	(3) All points <25' from forest margin. Points 1, 6 subject to shading. Near base of 50% slope.
9	7050	20	220	130-10	240	SW	850	120	500	(2) Tower centered in 30' diameter clearing.
10	6340	35	250	250-310	60	W	350	300	800	(3) Points 1, 4-6 <25' from forest margin. Points 4-6 subject to shading. 50-60% slope above installation.
11	5780	20	230	160-300	140	W	375	220	675	(4) Point 2 <25' from forest margin and subject to shading. All points <10' from alder thickets.
12	5309	15	190	110-300	190	W	225	170	750	(4) All points <25' from forest margin. Points 2, 3 subject to shading. Tree tops 40' + above anemometer. Some small trees, windfalls, alders in clearing.
13	5300	25-55	190-240	100-180 210-10	240	W	400	120	650	(3) Point 8 <25' from forest margin and subject to shading. Points 1, 2, 10, 11 on steeper slopes.
14	5150	(10)	(310)	-- GROUND WATER --						(7) On flood plain, <5' above W. Skyland Creek. Standing water nearby. Brushy. Near base of short 45% slope.
15	5250	<5	(240)	140-10	230	W	425	130	650	(3) All points <25' from forest margin. Points 2, 3, 4 subject to shading. In poorly drained shallow depression.
16	5150	(10)	(60)	110-310	10	-	50	350	800	(7) All points <6' above W. Skyland Creek. Near base of 40% slope.
17	5500	<5	(30)	340-20	40	N	150	320	950	(7) All points <2' above W. Skyland Creek. Thickets and windfalls. Near base of 60% slope.
18	5660	15	60	140-10	330	S, NW	400	130	550	(3) Points 3, 4, 5 <25' from forest margin and subject to shading. Thickets, windfalls, scattered small trees.
19	5900	10	120	120-30	270	S, NW	450	90	400	(1) Points 4-7 within 25' of low trees. Scattered windfalls in site area.
20	5950	SEE REMARKS		230-300 330-140	240	N	525	120	725	(3) All points <25' from forest margin. Points 2, 3 subject to shading. Tree tops 20' + above anemometer. On top small spur. Slopes to 50% on periphery, steepest to NE.
21	6000	20	40	220-160 200-290	280	N	600	80	350	(2) All points <25' from forest margin. Points 2, 3 subject to shading. 40% slopes below station.
22	6050	25	40-100	330-290	320	N	550	40	250	(2) All points <25' from forest margin. Points 1, 6, 7 subject to shading.
23	5770	20	90	320-130 220-260	210	NE	725	150	450	(1) Points 3, 4 <25' from trees and subject to shading. Alder thickets in station area. 40% slopes above station.
24	5280	20	150	270-130	220	NE	475	140	675	(3) Points 2, 3 <25' from forest margin and subject to shading. Anemometer near level of adjacent tree tops.
25	5290	See Remarks	360	270-130	220	NE	475	140	675	(3) Points 3, 4, 5, 6 <25' from forest margin and subject to shading. on surface, of approximately 10% slope, above drainage-way with side of 60% slope.
26	5295	5	90	70-180 230-330	210	NW	275	150	600	(6)
26A	5300	Aprx. 5	-	-- GROUND WATER --						(6)
27	5010	20	130	150-180	30	S	175	330	1100	(1) Point 3 <25' from group of trees. No points subject to shading. 60 to 70% slopes on valley sides above station. Points approximately 10' above Autumn Creek.
28	5350	-	-	170-210	40	S, NE	200	320	1300	(1)
29	6075	SEE REMARKS		no limits	360	SW, NE	925	0	0	(1) On top rounded grassy hill; highest elevation in Blacktail Hills. Nearest trees about 50' away and 10' high steepest slopes (approximately 40%) to south.
30	5480	10	260	220-360	140	-	325	220	575	(3) All points <25' from forest margin. Points 4, 5, 6 subject to shading. In shallow vale. Some ponding of water at times.
32	6625	10	130-210	130-250	120	S	825	240	1325	(1) All points <25' from groups of trees. Steeper slopes (up to 40%) above and below station area.
33	5355	5	140	40-270	230	SE	100	130	400	(2) All points <25' from forest margin and subject to shading. Points 6, 10 within forest. Near grass hummocks abundant.
34	4630	25	270	0-30 180-280	130	SW	175	290	675	(3)
36	5230	(5)	(110)	180-60	240	S, NE	25	120	275	(2) Snow stake in small clearing, subject to shading.
37	5250	(<5)	(128)	100-80	340	S, NE	50	20	150	(5)
38	4840	(5)	(320)	-- GROUND WATER --						(5) Near foot of 25% slope. <5' above Skyland Creek.
38A	4840	<5	(320)	-- GROUND WATER --						(2) <5' above Skyland Creek.
39	4925	<5	360	260-300 30-50	60	W	200	300	825	(6)
40	4925	<5	(360)	260-300 30-50	60	W	200	300	825	(6)

LEGEND AND DEFINITIONS

Elevation: Feet above mean sea level.
 Exposure Sector: That sector of a circle of approximately 1/2 mile radius, centered in the station area, within which there is no land >100' higher than the station. Azimuth limits = limits of sector, to nearest 10° Az. Size = angular size of sector. Dominant Direction = direction of most pronounced exposure, to nearest of 8 compass points. Lowest Point = difference in elevation between station and lowest point in exposure sector, to nearest 25'.
 Shelter Sector: The remaining sector of the circle, within which there is land >100' higher than the station. Size = 360° - exposure sector. Highest Point = difference in elevation between station and highest point in shelter sector, to nearest 25'.
 Slope: Mean slope of gradient line through a station point from 5' higher to 5' lower than point. Mean for all points of installation except where variation given, to nearest 5%.

$$\text{Slope} = \frac{\text{Vertical Interval}}{\text{Horizontal Interval}} \times 100$$

Aspect: Direction of slope at station points. Mean of all points except where variation given, to nearest 10° Az. Azimuth = clockwise angle from true N.
 () : Slope or aspect unsatisfactorily determined because of low gradients or local undulations of surface.

Vegetation and Remarks

- (1) In area of scattered trees and small groves.
 - (2) In clearing or near margin of forest of low (<30') trees.
 - (3) In clearing or near margin of forest of medium (30-50') trees.
 - (4) In clearing or near margin of forest of tall (>50') trees.
 - (5) Within forest or in relatively narrow (<15') passageway in forest of low trees.
 - (6) Within forest or in relatively narrow (<25') passageway in forest of medium trees.
 - (7) Within forest or in relatively narrow (<50') passageway in forest of tall trees.
- Points: Snow sampling points.
 Subject to shading: Subject to tree shading at times during middle part of day. (All points in (5), (6), (7) within 25' of forest margin and subject to shading).
 Ground cover: In station area mostly grasses and low shrubs except where noted.
 Forest = extensive area of moderate to high canopy cover (>30%).
 Conifers.
 # Station A - H is the site of measurements of incident radiation under a forest canopy.

